(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 959 227 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.11.1999 Bulletin 1999/47

(51) Int. Cl.[6]: F01B 3/00

(21) Application number: 99109847.6

(22) Date of filing: 19.05.1999

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 20.05.1998 JP 13853998
08.12.1998 JP 34841998

(71) Applicant:
Kabushiki Kaisha
Toyoda Jidoshokki Seisakusho
Aichi-ken (JP)

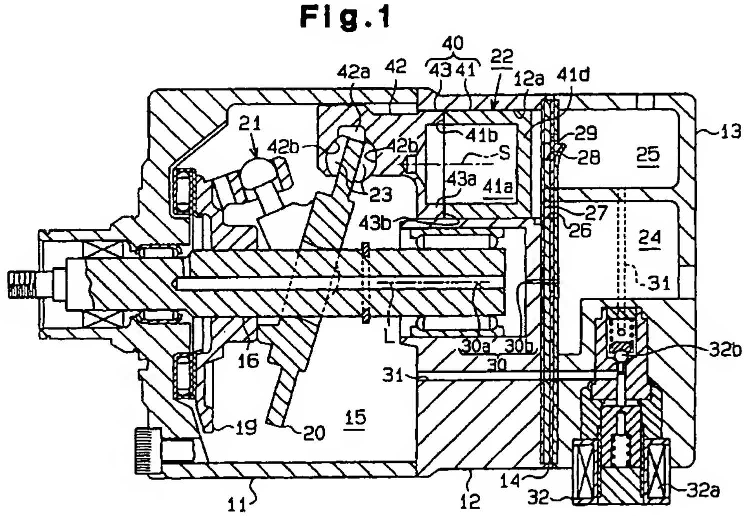
(72) Inventors:
- Kato, Takayuki,
c/o Toyoda Jidoshokki Seisakusho
Kariya-shi, Aichi-ken (JP)
- Sugioka, Takahiro,
c/o Toyoda Jidoshokki Seisakus.
Kariya-shi, Aichi-ken (JP)
- Takamatsu, Masato,
c/o Toyoda Jidoshokki Seisakus.
Kariya-shi, Aichi-ken (JP)
- Sekiguchi, Tsunehisa
Niwa-gun, Aichi-ken (JP)
- Ando, Masaki
Niwa-gun, Aichi-ken (JP)

(74) Representative:
Pellmann, Hans-Bernd, Dipl.-Ing. et al
Patentanwaltsbüro
Tiedtke-Bühling-Kinne & Partner
Bavariaring 4
80336 München (DE)

(54) Piston and method of manufacture

(57) A method for manufacturing improved pistons (22), which are reciprocated by a swash plate (20) in an compressor. Each piston (22) includes a head (40) and a skirt (42). The head (40) has a cylinder (41) with an open end, and the skirt (42) has a lid (43) for closing the open end of the cylinder (41). The lid (43) is friction welded to the cylinder (41). This method firmly joins the lid (43) to the cylinder (41) and reduces the cost and the time for manufacturing.

Fig.1



EP 0 959 227 A2

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to pistons for compressors that are used in vehicle air conditioners and to a method for manufacturing the pistons.

[0002] A typical compressor includes a cylinder block, which constitutes a part of the compressor housing. Cylinder bores are formed in the cylinder block. Each cylinder bore reciprocally houses a piston. Each piston has a metal head accommodated in the associated cylinder bore and a metal skirt coupled to a driving body (for example, a swash plate in a swash plate type compressor) . The head includes a hollow cylinder with a closed end and a lid to close the opening of the cylinder. The lid is integrally formed with the skirt.

[0003] Such pistons are known as hollow pistons. In comparison to solid pistons, which have solid heads, hollow pistons are light. Using hollow pistons therefore reduces weight. The head and the skirt of a solid piston are integrally formed, for example, by casting. However, the cylinder and the lid of a hollow piston must be separately formed and welded together.

[0004] Typically, the cylinder and the lid of a hollow piston are welded by electron-beam welding. In electron-beam welding, a highly accelerated electron-beam is irradiated onto parts to be welded in a vacuum welding chamber. However, electron-beam welding has the following drawbacks.

(1) The electron-beam welding apparatus has a vacuum container defining a welding chamber and an electron gun chamber, an exhaust mechanism, an electron gun, a high voltage power source and a controller. Accordingly, the electron-beam welding apparatus is fairly large, which increases manufacturing costs.

(2) The electron-beam must be continuously irradiated along the joint between the skirt and the cylinder of a piston. This complicates and slows the welding.

(3) Welding the skirt to the cylinder can produce bubbles in the metal forming the cylinder and the lid. This lowers the strength of the joint between the cylinder and the lid, deteriorates the appearance of the piston, and may prevent the piston from smoothly reciprocating.

SUMMARY OF THE INVENTION

[0005] Accordingly, it is an objective of the present invention to provide an inexpensive piston in which the cylinder and the lid are quickly and securely fixed to each other and a method for manufacturing such pistons.

[0006] To achieve the foregoing and other objectives and in accordance with the purpose of the present invention, a method for manufacturing a piston that cooperates with a driving body in a machine is provided. The piston has a skirt and a head. The skirt serves to connect the piston to the driving body, and the head includes a cylinder having at least one open end and a lid closing the open end. The method includes friction welding the lid to the cylinder.

[0007] The present invention is also embodied in a piston for cooperating with a driving body in a machine. The piston includes a skirt serving to connect the piston to the driving body and a head. The head includes a cylinder having at least one open end and a lid for closing the open end. The lid is friction welded to the cylinder.

[0008] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a cross-sectional view illustrating a variable displacement compressor having pistons according to a first embodiment of the present invention;

Fig. 2 is an exploded perspective view illustrating the piston of Fig. 1;

Fig. 3 is a timing chart showing a process for assembling the cylinder and the skirt of the piston of Fig. 1;

Fig. 4 is a cross-sectional view illustrating a piston according to a second embodiment;

Fig. 4A is an enlarged view of the area surrounded by the broken line circle of Fig. 4;

Fig. 5A is a cross-sectional view illustrating a method for assembling the cylinder and the skirt of the piston of Fig. 4;

Fig. 5B is an enlarged partial view of the area surrounded by the broken line circle of Fig. 5A;

Fig. 5C is a cross-sectional view illustrating a method for assembling the cylinder and the skirt of the piston of Fig. 4;

Fig. 5D is an enlarged partial view of the area surrounded by the broken line circle of Fig. 5C;

Fig. 6A is a cross-sectional view illustrating a method for assembling the cylinder and the skirt of a piston according to a third embodiment;

Fig. 6B is an enlarged partial view of the area indicated by the arrow of Fig. 6A;

Fig. 6C is a cross-sectional view illustrating a method for assembling the cylinder and the skirt of the cylinder according to the third embodiment;

Fig. 6D is an enlarged partial view of the area indicated by the arrow of Fig. 6C;

Fig. 7A is a cross-sectional view illustrating a method for assembling the cylinder and the skirt of a piston according to a fourth embodiment;

Fig. 7B is a partial cross-sectional view illustrating a roller, which differs from that of Fig. 7A;

Fig. 7C is a partial cross-sectional view illustrating a roller, which differs from that of Figs. 7A and 7B;

Fig. 8 is a cross-sectional view illustrating a piston according to a fifth embodiment;

Fig. 9 is a cross-sectional view illustrating a piston according to a sixth embodiment;

Fig. 10 is a cross-sectional view illustrating a piston according to a seventh embodiment;

Fig. 11 is a cross-sectional view illustrating a piston according to an eighth embodiment; and

Fig. 12 is a cross-sectional view illustrating a piston according to a ninth embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Pistons according to a first embodiment will now be described with reference to Figs. 1-3. The pistons are used in variable displacement compressors for vehicle air conditioners.

[0011] As shown in Fig. 1, a front housing 11 and a rear housing 13 are secured to a cylinder block 12. A valve plate 14 is located between the cylinder block 12 and the rear housing 13. A crank chamber 15 is defined by the inner walls of the front housing 11 and the front end face of the cylinder block 12.

[0012] A drive shaft 16 is rotatably supported by the front housing 11 and the cylinder block 12. The drive shaft 16 is coupled to an external drive source (not shown), or a vehicle engine, by a clutch mechanism such as an electromagnetic clutch. When the engine is running, the clutch operably connects the shaft 16 with the engine thereby rotating the shaft 16.

[0013] A rotor 19 is fixed to the drive shaft 16 in the crank chamber 15. The crank chamber 15 also accommodates a swash plate 20. The swash plate 20 is supported on the drive shaft 16 to slide along the drive shaft 16 and incline with respect to the axis L of the drive shaft 16. A hinge mechanism 21 is located between the rotor 19 and the swash plate 20 to rotate the swash plate 20 integrally with the drive shaft 16. The hinge mechanism 21 guides the movement of the swash plate 20 in the axial direction of the drive shaft 16 and the inclination of the swash plate 20 with respect to the drive shaft 16. The inclination of the swash plate 20 decreases as the swash plate 20 moves toward the cylinder block 12 and increases as the swash plate 20 moves toward the rotor 19.

[0014] Cylinder bores 12a are formed in the cylinder block 12. Each cylinder bore 12a houses a single-headed hollow piston 22. Each piston 22 is coupled to the swash plate 20 by way of a pair of shoes 23. The shoes 23 convert rotation of the swash plate 20 into reciprocation of each piston 22 in the associated cylinder bore 12a.

[0015] A suction chamber 24 and a discharge chamber 25 are defined in the rear housing 13. The valve plate 14 has suction ports 26, suction valve flaps 27, discharge ports 28 and discharge valve flaps 29. Each set of ports 26, 28 and valve flaps 27, 29 corresponds to one of the cylinder bores 12a. As each piston 22 moves from the top dead center to the bottom dead center, refrigerant gas is drawn into the corresponding suction port 26 from the suction chamber 24 thereby opening the suction flap 27 to enter the associated cylinder bore 12a. As each piston 22 moves from the bottom dead center to the top dead center in the associated cylinder bore 12a, the gas in the cylinder bores 12a is compressed to a predetermined pressure. The gas is then discharged to the discharge chamber 28 through the associated discharge port 28 while causing the associated valve flap 29 to flex to an open position.

[0016] A bleeding passage 30 includes a passage 30a formed in the drive shaft 16 along its axis and a passage 30b formed in the cylinder block 12 and the valve plate 14. The bleeding passage 30 connects the crank chamber 15 with the suction chamber 24. A supply passage 31 connects the discharge chamber 25 with the crank chamber 15. A displacement control valve 32 is accommodated in the rear housing 13 to regulate the supply passage 31.

[0017] The displacement control valve 32 includes a solenoid 32a and a valve body 32b. Excitation and de-excitation of the solenoid 32a causes the valve body 32b to open and close the supply passage 31. The control valve 32 is connected to a computer (not shown). The computer excites and de-excites the solenoid 32a

in accordance with the cooling load, which moves the valve body 32b. Accordingly, the control valve 32 regulates flow of refrigerant gas from the discharge chamber 25 to the crank chamber 15, which controls the difference between the pressure of the crank chamber 15 and the pressure of the cylinder bores 12a. The inclination of the swash plate 20 is altered in accordance with changes in the pressure difference. This, in turn, alters the stroke of the pistons 22 and varies the displacement of the compressor.

[0018] When the solenoid 32a is de-excited, the valve body 32b opens the supply passage 31 thereby communicating the discharge chamber 25 with the crank chamber 15. The refrigerant gas in the discharge chamber 25 therefore flows into the crank chamber 15 through the supply passage 31, which raises the pressure in the crank chamber 15. As a result, the inclination of the swash plate 20 decreases, and the stroke of the pistons 22 decreases, accordingly. This decreases the displacement of the compressor.

[0019] When the solenoid 32a is excited, the valve body 32b closes the supply passage 31. This stops the flow of refrigerant gas from the discharge chamber 25 to the crank chamber 15. Refrigerant gas in the crank chamber 15 flows to the suction chamber 24 through the bleeding chamber 30, which lowers the pressure of the crank chamber 15. As a result, the inclination of the swash plate 20 is increased and the stroke of the pistons 22 increases, accordingly. This increases the displacement of the compressor.

[0020] In this manner, the inclination of the swash plate 20 is changed in accordance with the changes in the pressure of the crank chamber 15. The stroke of the pistons 22 changes in accordance with the inclination of the swash plate 20. Hollow pistons are relatively light and therefore have a small inertial force when reciprocated. Therefore, when hollow pistons are used, the swash plate 20 can be moved to a desired inclination position without being significantly affected by the inertial force of the pistons 22.

[0021] The structure of each piston 22 will now be described with reference to Figs. 1 to 3.

[0022] As shown in Figs. 1 and 2, each piston 22 has a head 40 housed in the associated cylinder bore 12a and a skirt 42 coupled to the swash plate 20 by the shoes 23. The head 40 and the skirt 42 are joined to each other to form the piston 22. The head 40 includes a cylinder 41 and a disk-shaped lid 43. The cylinder 41 includes an end plate 41d for closing the end that faces the valve plate 14. A slot 42a, which faces the swash plate 20, is provided in the skirt 42. The slot 42a has a pair of opposing walls. A socket 42b is defined in each wall to receive a shoe 23. A pair of shoes 23 are supported by the sockets 42b. The shoes 23 sandwich a peripheral portion of the swash plate 20 as shown in Fig 1.

[0023] The lid 43 is formed integrally with the skirt 42. A boss 43a extends from the lid 43. The outer diameter of the boss 43a is substantially the same as the outer diameter of the cylinder 41. The inner diameter of the boss 43a is substantially the same as the inner diameter of the cylinder 41. The cylinder 41 and the skirt 42 are made by casting or forging metal such as aluminum or aluminum alloy.

[0024] The cylinder 41 and the lid 43 are fixed to each other by friction welding. First, as shown in Fig. 2, the cylinder 41 and the skirt 42 are aligned such that the end surface 41b of the cylinder 41 faces the end surface 43b of the boss 43a. Either the cylinder 41 or the skirt 42 is rotated relative to the other about an axis S of the piston 22. The cylinder 41 and the skirt 42 are then brought into contact with each other. The relative rotational speed of the cylinder 41 and the skirt 42 and the contact pressure between the cylinder 41 and the skirt 42 change as shown in the graph of Fig. 3.

[0025] When the pressure between the end surfaces 41b, 43b reaches a first predetermined pressure P1, the pressure is maintained for a predetermined time period. Since the cylinder 41 and the skirt 42 are pressed against each other, the relative rotation heats the end surfaces 41b, 43b. The relative rotation is then stopped. Thereafter, the contact pressure applied to the cylinder 41 and the skirt 42 is increased to a second pressure P2, which is greater than the first level P1. This causes a kind of seizing between the end surfaces 41b, 43b thereby welding the cylinder 41 to the skirt 42.

[0026] The cylinder 41 is welded to the skirt 42 under atmospheric pressure. Therefore, when the joint between cylinder 41 and the skirt 42 is heated, the metal forming the cylinder 41 and the skirt 42 is not deteriorated by bubbles.

[0027] The embodiment of Figs. 1 to 3 has the following advantages.

(1) The cylinder 41 and the skirt 42 are fixed to each other by friction welding. Compared to electron-beam welding, friction welding does not require a large welding apparatus, which reduces the cost of the pistons 22. The cylinder 41 and the skirt 42 are rotated relative to each other and the entire end surfaces 41b, 43b are welded together simultaneously. This shortens the welding time compared to electron-beam welding, in which an electron-beam is directed along the annular joint between the cylinder 41 and the skirt 42.

(2) The cylinder 41 and the skirt 42 are rotated relative to each other while being pressed against each other by the first pressure P1. Then, the relative rotation is stopped and the cylinder 41 and the skirt 42 are pressed against each other by the second pressure P2, which is greater than the first pressure P1. This ensures seizing between the end surfaces 41b and 43b. The cylinder 41 and the skirt 42 are therefore firmly fixed to each other.

[0028] Figs. 4 to 5D illustrate a method for assembling a piston according to a second embodiment. The differences from the embodiment of Figs. 1-3 will mainly be discussed below. The outer diameter of the boss 43a is substantially the same as the inner diameter of the cylinder 41. Annular grooves 43c, the number of which is two in the embodiment of Figs. 4 to 5D, are formed in the outer surface of the boss 43a.

[0029] The cylinder 41 and the skirt 42 are fixed to each other by plastic flow and adhesive. Adhesive is applied to the circumference of the boss 43a and to the part of the lid 43 that faces the adjacent end surface 41b of the cylinder 41. The adhesive is, for example, resin adhesive such as epoxy, polyamide or vinyl acetate.

[0030] Then, the skirt 42 is attached to the cylinder 41 such that the lid 43 closes the inner space 41a of the cylinder 41. At this time, the outer circumferential surface of the boss 43a contacts the inner wall of the cylinder 41, and the lid 43 contacts the end surface 41b of the cylinder 41.

[0031] Then, as shown in Figs. 5A and 5C, the cylinder 41 and the lid 43 are passed through a die 201, the inner diameter of which is slightly smaller than the outer diameter of the cylinder 41 and the lid 43. The die 201 strongly presses the cylinder 41 against the boss 43a, which causes plastic flow of the metal forming the cylinder 41 into the grooves 43c. Further, when set, the adhesive reinforces the joint between the cylinder 41 and the skirt 42. The cylinder 41 is fixed to the skirt 42 under atmospheric pressure. Therefore, the metal forming the cylinder 41 and the skirt 42 is not deteriorated by bubbles. In Fig. 5A, the difference between the inner diameter of the die 201 and the outer diameter of the cylinder 41 and the lid 43 is illustrated in an exaggerated manner.

[0032] Like the embodiment of Figs. 1 to 3, the embodiment of Figs. 4 to 5D reduces the manufacturing cost and shortens the manufacturing time. Also, the embodiment of Figs. 4 to 5D has the following advantages.

(1) The cylinder 41 and the skirt 42 are fixed to each other by two devices, namely plastic flow and adhesive. Thus, the cylinder 41 and the skirt 42 are firmly secured to each other.

(2) The annular grooves 43c are formed on the boss 43a of the lid 43. The grooves 43c complicate the shape of the joint between the cylinder 41 and the skirt 42, which firmly secures the cylinder 41 and the skirt 42 to each other.

[0033] The cylinder 41 and the skirt 42 may be assembled without using adhesive. That is, the cylinder 41 and the skirt 42 may be joined only by plastic flow.

[0034] Figs. 6A to 6D illustrate a method for assembling a piston according to a third embodiment. The differences from the embodiment of Figs. 4 to 5D will mainly be discussed below. The boss 43a of the embodiment of Figs. 6A to 6D has no annular grooves 43c. As shown in Fig. 6B, solder R fills the space between the cylinder 41 and the boss 43a. The solder R is an alloy having a lower melting point than that of the metal forming the cylinder 41 and the skirt 42. The solder R may be applied either to the cylinder 41 or to the boss 43a prior to the assembly. Alternatively, the solder R may be formed like a ring and be fitted to the cylinder 41 or the boss 43a. Further, cylinder 41 or the lid 43 may be coated with powdered solder R.

[0035] Like the embodiment of Figs. 4 to 5D, a die 201 is used in the embodiment of Figs. 6A to 6D. The die 201 strongly presses the cylinder 41 against the boss 43a thereby causing a plastic flow between the cylinder 41 and the boss 43a. This creates a number of lattice defects in the metal forming the cylinder 41 and the skirt 42. In other words, holes are formed in the metal. As a result, the atoms of the metal forming the cylinder 41 enter the lattice defects in the skirt 42, and the atoms of the metal forming the skirt 42 enter the lattice defects in the cylinder 41.

[0036] Passing the piston 22 through the die 201 applies pressure to the joint between the cylinder 41 and the skirt 42, thereby generating heat. The pressure and the heat diffuse the solder R thereby causing the solder R to enter the lattice defects. Further, the piston 22 is heated by an external heat source when being passed through the die 201. The heat of the heat source, together with the heat caused by the pressure at the joint, raises the temperature of the solder R above its melting point, which liquefies the solder R. The liquefied solder R is diffused at the joint. The external heat may be omitted, in which case a solidus diffusion of the solder R occurs.

[0037] As diagrammatically shown in Fig. 6D, an alloy layer G is formed at the joint between the cylinder 41 and the skirt 42. The layer G includes the metal forming the cylinder 41 and the skirt 42 and the solder R. The cylinder 41 and the skirt 42 are fixed to each other by the alloy layer G such that there is no boundary between the cylinder 41 and the skirt 42.

[0038] The inner diameter of the die 201, or the pressure applied to the cylinder 41 and the skirt 42 when the piston 22 is passed through the die 201, is determined such that the strain of the joint between the cylinder 41 and the skirt 42 is three to fifteen percent. For example, if the applied pressure is too small, that is, if the strain of the joint is smaller than three percent, the number of lattice defects will not be sufficient. In other words, there will not be enough holes and the metal atoms in the cylinder 41 and the skirt 42 will not sufficiently interweave. Also, inadequate pressure prevents the solder R from being satisfactorily diffused, which weakens the strength of the joint between the cylinder 41 and the skirt 42. Since inadequate pressure slows the diffusion of the solder R, the cylinder 41 must be passed through the die 201 relatively slowly. On the other hand, if the

applied pressure is relatively great, that is, if the strain of the joint exceeds fifteen percent, the piston 22 is greatly deformed and the piston 22 will require machining.

[0039] After assembling the piston 22 with the die 201, the joint between the cylinder 41 and the skirt 42 is heated again. The temperature is preferably higher than the melting point of the layer G. The heat promotes the diffusion of the alloy layer G thereby enforcing the joint between the cylinder 41 and the skirt 42. A laser heater or an electron-beam heater may be used to apply the heat to the joint between the cylinder 41 and the lid 43 by. Alternatively, the whole piston 22 may be placed in a furnace.

[0040] The cylinder 41 and the skirt 42 are manufactured by forging or casting. The cylinder 41 and the skirt 42 are then hardened and tempered. Thereafter, the cylinder 41 is passed through the die 201. Re-heating the piston 22 in a furnace allows the tempering process to be omitted.

[0041] The cylinder 41 and the skirt 42 are preferably made of the same or different aluminum alloys selected from the alloys specified in Japanese Industrial Standard (JIS) A2017, A2014, A4032, A6063, A6061, A7075, ADC12 and A390. The materials that are suitable for the solder R are as follows:

an alloy including zinc as a first principal component, tin as a second principal component, aluminum as a third principal component and copper, chromium and beryllium as additives;

an alloy including tin as a first principal component, zinc as a second principal component and aluminum, copper and beryllium as additives.

an alloy including tin as a first principal component, zinc as a second principal component and aluminum, copper, chromium and beryllium as additives;

an alloy including tin as a first principal component, zinc as a second principal component and copper and silver as additives;

an alloy including zinc as a first principal component, aluminum as a second principal component, tin as a third principal component and cadmium, copper, titanium and beryllium as additive;

an alloy including zinc as a first principal component, tin as a second principal component and copper and cadmium as additives;

an alloy including zinc as a first principal component, aluminum as a second principal component and silicon, copper and titanium as additives;

an alloy including zinc as a first principal component, aluminum as a second principal component and titanium, beryllium and copper as additives;

an alloy including zinc as a first principal component, aluminum as a second principal component and titanium, cadmium and copper as additives; and

an alloy including zinc as a first principal component, aluminum as a second principal component and copper, chromium, magnesium and tin as additives.

[0042] In the solder R, the percentage by weight of the first principal component is greater than or equal to the percentage by weight of the second principal component, and the percentage by weight of the second principal component is greater than or equal to the percentage by weight of the third principal component (if a third principle component is present. The percentage by weight of the additives are extremely small relative to those of the principal components.

[0043] In the embodiment of Figs. 6A to 6D, the joint of the cylinder 41 and the skirt 42 is pressed by the die 201. This generates plastic flow at the joint thereby promoting the diffusion of the solder R. Compared to simple soldering in which the joint is not pressed, the embodiment of Figs. 6A to 6D enforces the joint between the cylinder 41 and the skirt 42.

[0044] In a fourth embodiment illustrated in Figs. 7A to 7C, the die 201 of the embodiment shown in Figs. 4 to 6D is replaced with rollers 202. The piston 22 is rotated about its axis. At the same time, the rollers 202 are strongly pressed against the joint between the cylinder 41 and the boss 43a. This generates a plastic flow at the joint. The piston 22 shown in Fig. 7A has grooves formed on the circumference of the boss 43a like the piston 22 of Fig. 4. However, the grooves may be omitted. As in the embodiments of Figs. 4 to 5D, adhesive may be used in the embodiment of Fig. 7A. Also, as in the embodiment of Figs. 6A to 6D, solder may be used in the embodiment of Fig. 7A.

[0045] The diameter of each roller 202 shown in Fig. 7A is constant along its axis. In other words, the surface of the roller 202 is cylindrical. Thus, the entire circumferential surface of the roller 202 is pressed against the piston 22. When using such rollers 202 for assembling, the piston 22 is heated to a relatively high temperature and the rollers 202 are pressed against the piston 22 by relatively small pressure. Further, the assembly takes a relatively long period. Specifically, in each roller 202 in Fig. 7A, the pressing force of the roller 202 per unit area is relatively small, which generates relatively small plastic flow at the joint. On the other hand, the large pressing area of the roller 202 of Fig. 7A and the long assembly time increase the temperature at the joint. Therefore, if used, solder is smoothly diffused. The axial length of the rollers 202 is determined such that the plastic flow at the joint is sufficient to ensure the

strength of the joint and that no plastic flow occurs in the other part of the piston.

[0046] Fig. 7B shows another type of roller 202. The circumferential surface of the roller 202 of Fig. 7B is circularly curved so that the axial center of the roller 202 is recessed. The radius of curvature R2 at the axial ends of the roller 202 may be extremely small. When using the rollers 202 of Fig. 7B, the piston 22 is heated to a relatively low temperature and the rollers 202 are pressed against the piston 22 by a relatively great pressure. Further, the process takes a relatively short time. Compared to the case where the rollers 202 of Fig. 7A are used, plastic flow at the joint is highly promoted and the joint is not heated to a high temperature. The shape of the roller 202, specifically a radius of curvature R1 of the recess in the axial center is optimized to effectively generate plastic flow at the joint thereby minimizing the energy required to couple the cylinder 41 with the skirt 42.

[0047] Fig. 7C shows another type of roller 202. The circumferential surface of the roller 202 of Fig. 7C is tapered by a predetermined angle θ. When using the rollers 202 of Fig. 7C, the piston 22 is heated to a relatively low temperature and the rollers 202 are pressed against the piston 22 by a relatively great pressure. Further, the process is performed in a relatively short time. Plastic flow at the joint is highly promoted and the joint is not heated to a high temperature. The angle θ is optimized to effectively generate plastic flow at the joint thereby minimizing the energy required to couple the cylinder 41 with the skirt 42.

[0048] In embodiments shown in Figs. 8 to 12, the skirt 42 and the head 41 of each piston 22 are integrally formed, and the end plate 41d is separately formed from the cylinder 41. The cylinder 41 and the end plate 41d are coupled to each other by friction welding or plastic flow as shown in Figs. 1 to 7C.

[0049] Fig. 8 illustrates a method for manufacturing a piston 22 according to a fifth embodiment. The end plate 41d is disk shaped. The end surface 41e of the cylinder 41 and the end surface 41f of the end plate 41d are brought into contact. Then, the cylinder 41 and the end plate 41d are coupled to each other either by friction welding or by plastic flow.

[0050] Fig. 9 illustrates a piston 22 according to a sixth embodiment. The end plate 41 includes a boss 41g. The outer diameter of the boss 41g is substantially the same as the inner diameter of the cylinder 41. The boss 41g is fitted into the cylinder 41 such that the end surfaces 41e and 41f contact each other. Then, the cylinder 41 and the end plate 41d are coupled to each other either by friction welding or by plastic flow.

[0051] Fig. 10 illustrates a piston 22 according to a seventh embodiment. A cylindrical portion 41h is integrally formed with the end plate 41. The outer diameter of the cylindrical portion 41h is the same as that of the cylinder 41. The end surface 41m of the cylindrical portion 41h and the end surface 41e of the cylinder 41 are brought into contact. Then, the cylinder 41 and the end plate 41d are coupled to each other either by friction welding or by plastic flow.

[0052] Fig. 11 illustrates a piston 22 according to an eighth embodiment. The piston 22 of Fig. 11 is a modification of the piston of Fig. 10. That is, the cylindrical portion 41h of the end plate 41d includes a boss 41i. The outer diameter of the boss 41i is smaller than the rest of the cylindrical portion 41h. The cylinder 41 has connector portion 41j formed at the open end. The inner diameter of the connector portion 41j is substantially the same as the outer diameter of the boss 41i. The boss 41i is fitted in the connector portion 41j such that the end surfaces 41e of the cylinder 41 contact the end surfaces 41m of the cylindrical portion 41e. Then, the cylinder 41 and the end plate 41d are coupled to each other either by friction welding or by plastic flow.

[0053] Fig. 12 illustrates a piston 22 according to a ninth embodiment. The piston 22 of Fig. 12 is a modification of the piston of Fig. 10. That is, the inner diameter of the cylindrical portion 41h is larger than the inner diameter of the cylinder 41. The cylinder 41h includes a boss 41n at the open end. The outer diameter of the boss 41n is substantially the same as the inner diameter of the cylindrical portion 41h. The boss 41n is fitted in the cylindrical portion 41h such that the end surfaces 41e of the cylinder 41 contact the end surfaces 41m of the cylindrical portion 41h. Then, the cylinder 41 and the end plate 41d are coupled to each other either by friction welding or by plastic flow.

[0054] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Particularly, it should be understood that the invention may be embodied in the following forms.

[0055] In the embodiments of Figs. 1 to 7C, either the cylinder 41, the skirt 42 or both may be made of metal other than aluminum and aluminum alloy, such as iron, iron alloy, copper or copper alloy. Likewise, in the embodiments of Figs. 8 to 12, either the cylinder 41, the end plate or both may be made of metal other than aluminum and aluminum alloy, such as iron, iron alloy, copper or copper alloy.

[0056] The present invention may be embodied in pistons other than the pistons 22 of Figs. 1 to 12, which are used in swash plate compressors. For example, the present invention may be embodied in pistons of wave cam plate type compressors, pistons of double-headed piston type variable displacement compressor, pistons in air compressors and pistons in reciprocation internal combustion engines.

[0057] Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

[0058] A method for manufacturing improved pistons

(22), which are reciprocated by a swash plate (20) in an compressor. Each piston (22) includes a head (40) and a skirt (42). The head (40) has a cylinder (41) with an open end, and the skirt (42) has a lid (43) for closing the open end of the cylinder (41). The lid (43) is friction welded to the cylinder (41). This method firmly joins the lid (43) to the cylinder (41) and reduces the cost and the time for manufacturing.

Claims

1. A method for manufacturing a piston (22) that cooperates with a driving body (20) in a machine, wherein the piston (22) has a skirt (42) and a head (40), the skirt (42) serves to connect the piston (22) to the driving body (20), and the head (40) includes a cylinder (41) having at least one open end and a lid (43; 41d) closing the open end, the method **characterized by**:

   friction welding the lid to the cylinder.

2. The method according to claim 1, **characterized by** generating relative rotation of the lid (43; 41d) and the cylinder (41) for a predetermined time while pressing the lid (43; 41d) and the cylinder (41) against each other with a predetermined force.

3. The method according to claim 2, **characterized by** pressing the lid (43; 41d) and the cylinder (41) against each other in the axial direction of the piston (22) and generating relative rotation of the lid (43; 41d) and the cylinder (41) about the axis of the piston (22).

4. The method according to claim 2, **characterized by** pressing the lid (43; 41d) and the cylinder (41) against each other with a force greater than the predetermined force after generating the relative rotation of the lid (43; 41d) and the cylinder (41).

5. The method according any one of claims 1 to 4, **characterized in that** the method is performed under atmospheric pressure.

6. A method for manufacturing a piston (22) that cooperates with a driving body (20) in a machine, wherein the piston has a skirt (42) and a head (40) , the skirt (42) serves to connect the piston (22) to the driving body (20) , and the head (40) includes a cylinder (41) having at least one open end and a lid (43; 41d) closing the open end, the method **characterized by**:

   generating a plastic flow between the lid and the cylinder to join the lid to the cylinder.

7. The method according to claim 6, **characterized by** pressing the lid (43; 41d) and the cylinder (41) against each other to generate a plastic flow between the lid (43; 41d) and the cylinder (41).

8. The method according to claim 7, **characterized by**:

   forming a cylindrical boss (43a) to the lid (43; 41d) ;
   fitting the cylindrical boss (43a) into the opening of the cylinder (41); and
   radially pressing the cylinder (41) against the cylindrical boss (43a) to generate the plastic flow between the cylinder (41) and the cylindrical boss (43a).

9. The method according to claim 8, **characterized by** forming an annular groove (43c) on the outer surface of the cylindrical boss (43a), wherein, when the cylinder (41) is radially pressed against the cylindrical boss (43a), part of the cylinder (41) located about the cylindrical boss (43a) enters the annular groove (43c) by plastic flow.

10. The method according to claim 8, **characterized by** passing the cylinder (41) through a die (201) to radially press the cylinder (41) against the cylindrical boss (43a) , wherein the inner diameter of the die (201) is slightly smaller than the outer diameter of the cylinder (41).

11. The method according to claim 8, **characterized by** rotating the cylinder about the axis of the cylinder (41) while pressing a roller (202) against the cylinder (41).

12. The method according any one of claims 6 to 11, **characterized by** applying adhesive between the lid (43; 41d) and the cylinder (41).

13. The method according any one of claims 7 to 11, **characterized by** applying solder between the lid (43; 41d) and the cylinder (41).

14. The method according to claim 6, **characterized by** heating the solder to a temperature that is higher than the melting point of the solder while pressing the lid (43; 41d) and the cylinder (41) against each other.

15. The method according any one of claims 6 to 11, **characterized in that** the method is performed under atmospheric pressure.

16. A piston (22) for cooperating with a driving body (20) in a machine, the piston (22) **characterized by**:

a skirt (42), wherein the skirt (42) serves to connect the piston (22) to the driving body (20) ; and
a head (40), wherein the head (40) includes:

a cylinder (41) having at least one open end; and
a lid (43; 41d) for closing the open end, wherein the lid (43; 41d) is friction welded to the cylinder (41).

17. A piston (22) for cooperating with a driving body (20) in a machine, the piston (22) including:

a skirt (42), wherein the skirt (42) serves to connect the piston (22) to the driving body (20) ; and
a head (40), wherein the head (40) includes:

a cylinder (41) having at least one open end; and
a lid (43; 41d) for closing the open end, wherein the lid (43; 41d) is joined to the cylinder (41) by plastic flow between the lid (43; 41d) and the cylinder (41).

Fig.1

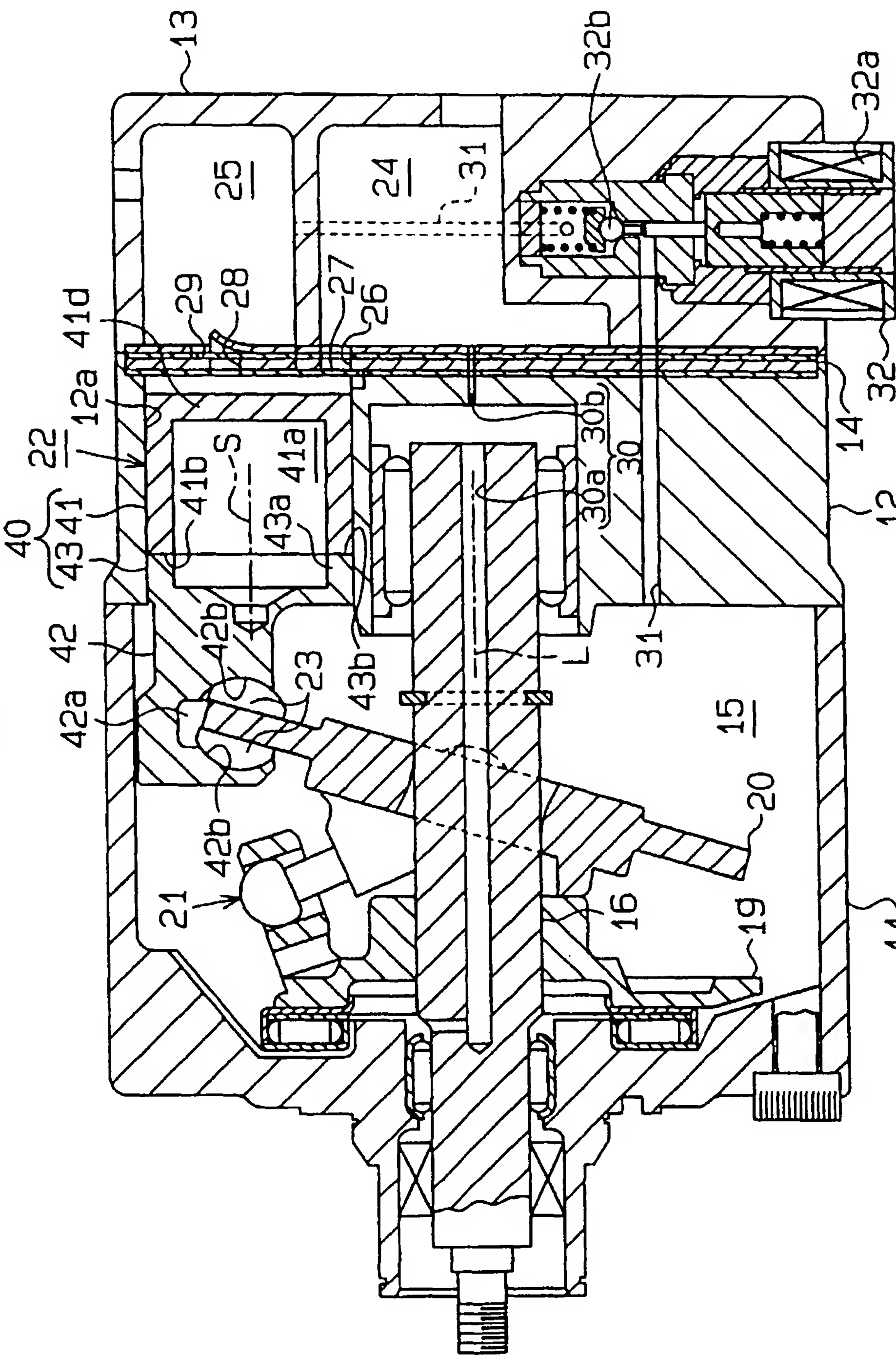

13
32b
32a
25
24
31
29
28
27
26
41d
12a
22
41b
S
41a
40
43
41
43a
30b
30a
30
14
32
12
42
42b
43b
23
31
L
42a
15
20
42b
21
16
19
11

Fig.2

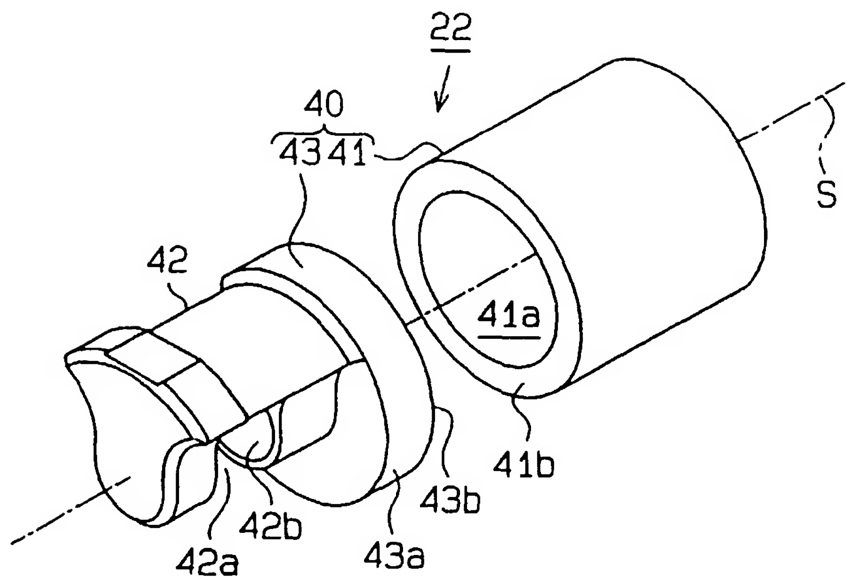

22
40
43
41
S
42
41a
41b
43b
42b
42a
43a

Fig.3

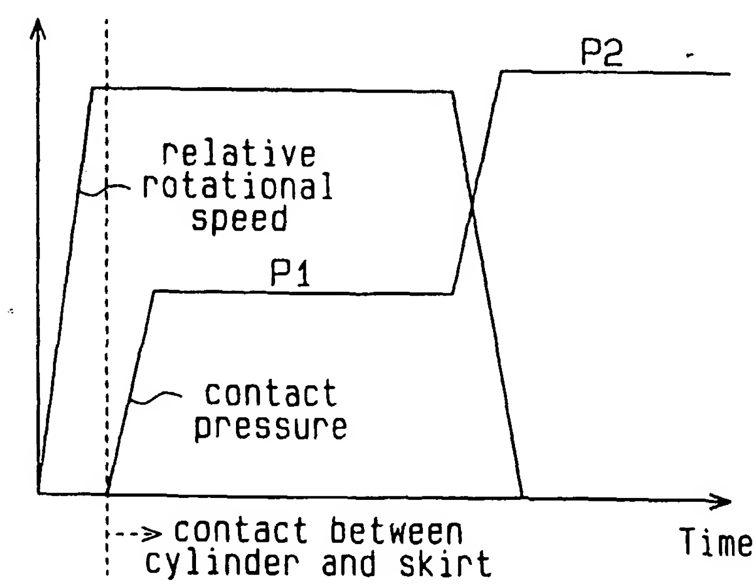

P2
relative
rotational
speed
P1
contact
pressure
--> contact between
cylinder and skirt
Time

Fig.4A

Fig.4

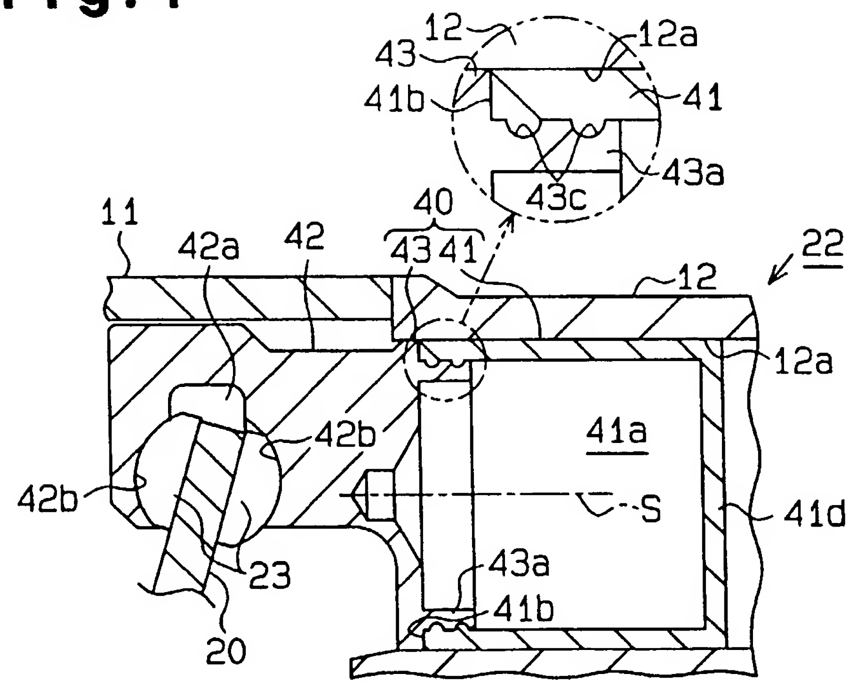

12
43
12a
41b
41
43a
43c
40
11
42a
42
43 41
22
12
12a
41a
42b
42b
S
41d
23
43a
41b
20

Fig.5A

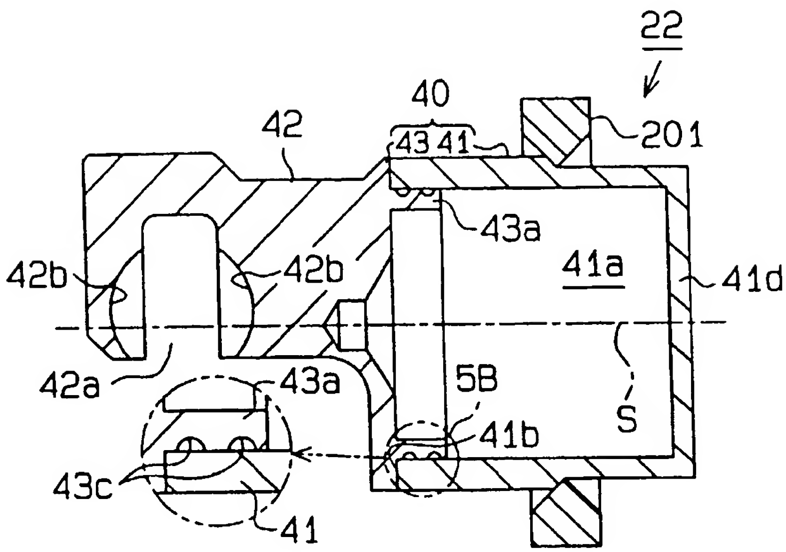


Fig.5B

Fig.5C

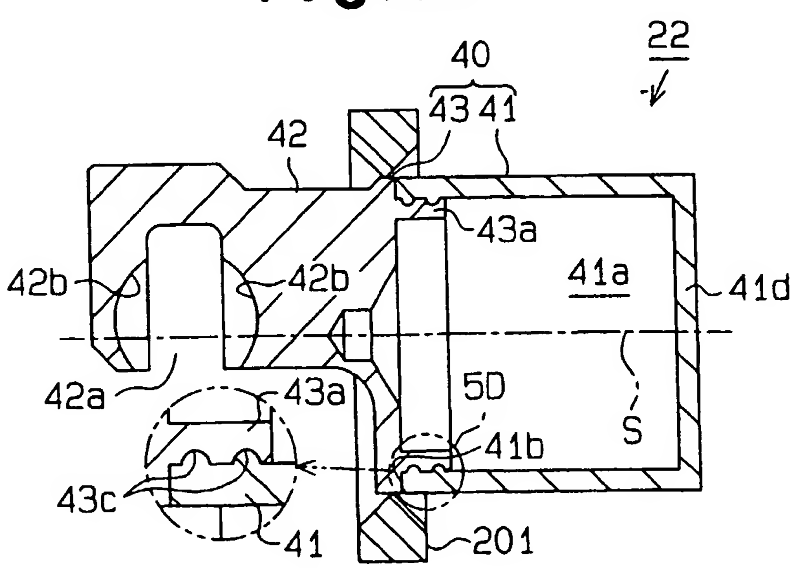


Fig.5D

Fig.6A

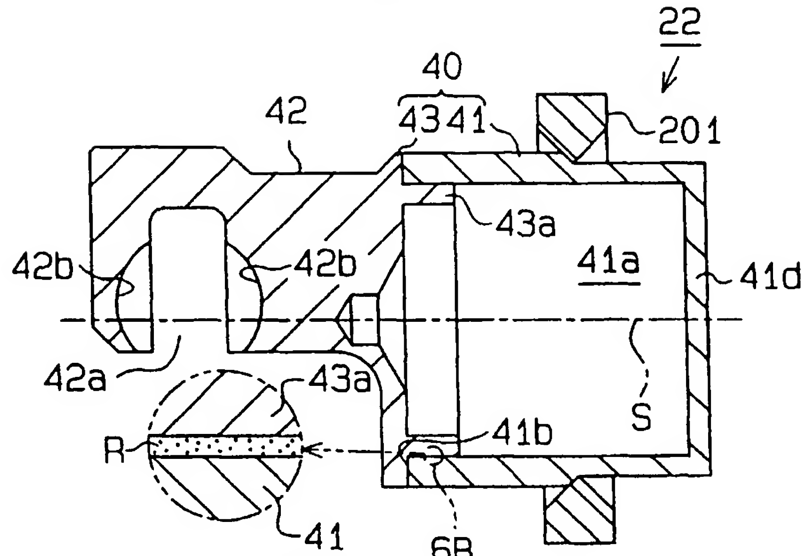


Fig.6B

Fig.6C

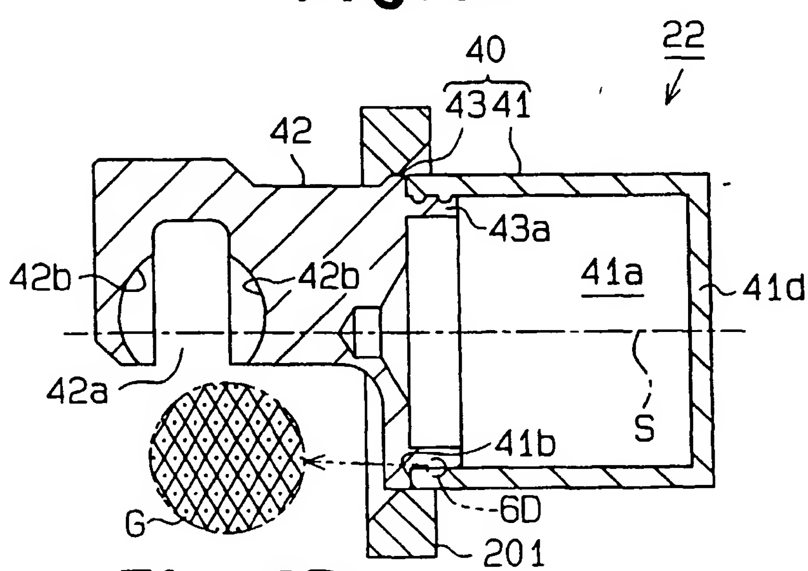


Fig.6D

Fig.7A

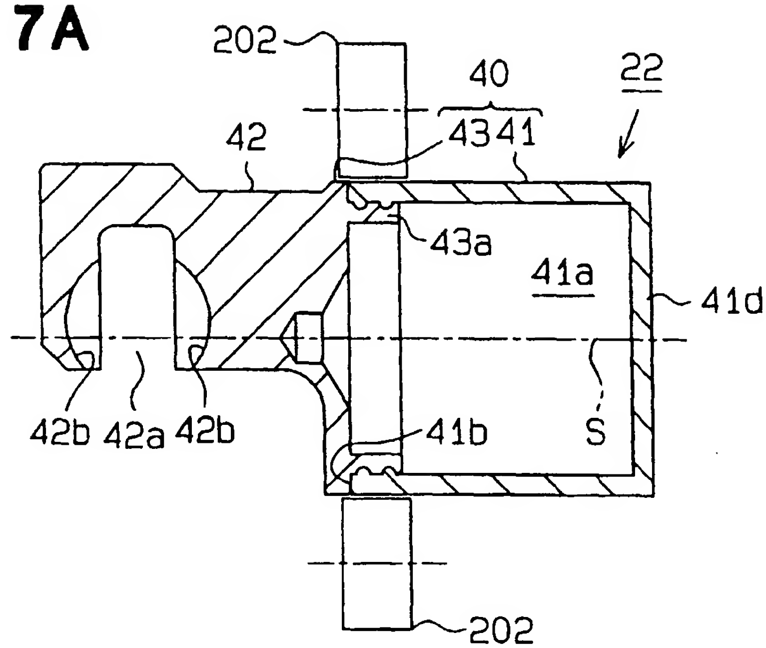


Fig.7B

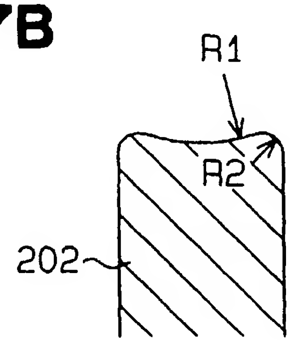


Fig.7C

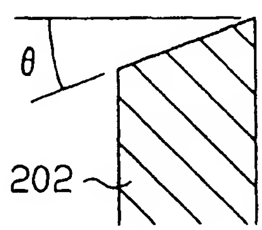


Fig.8

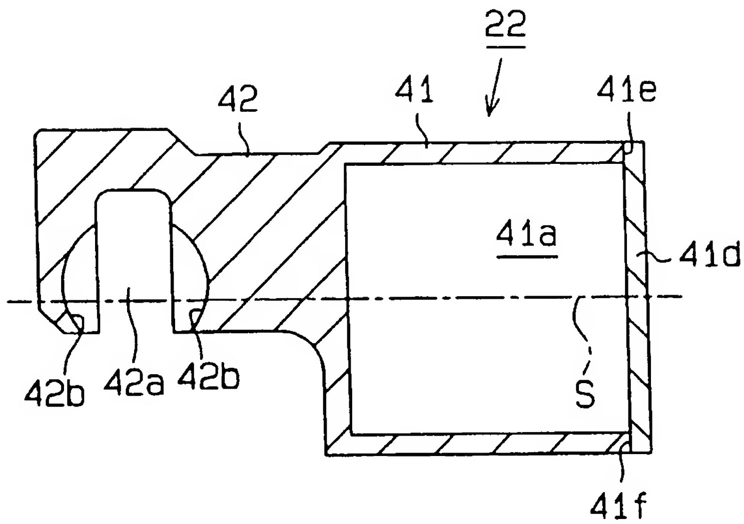

22
42
41
41e
41a
41d
S
42b
42a
42b
41f

Fig.9

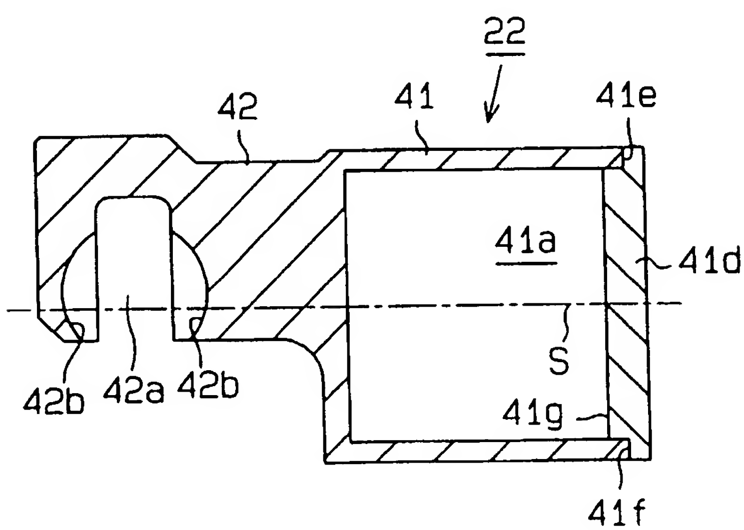

22
42
41
41e
41a
41d
S
41g
42b
42a
42b
41f

Fig.10

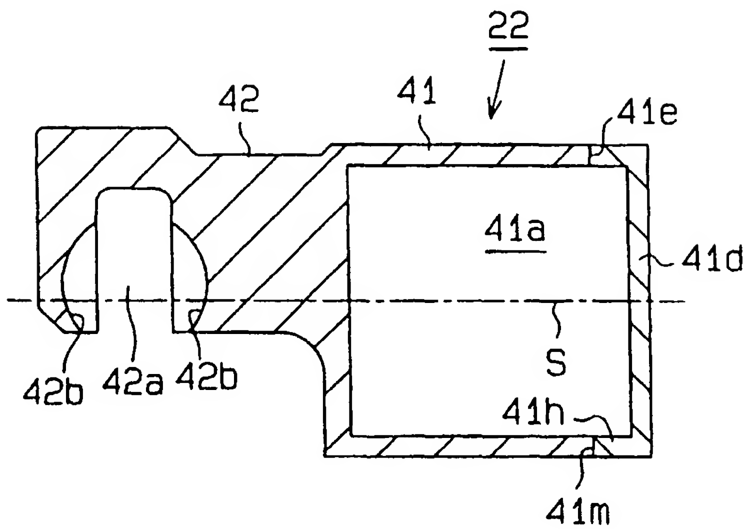

22
42
41
41e
41a
41d
S
42b
42a
42b
41h
41m

Fig.11

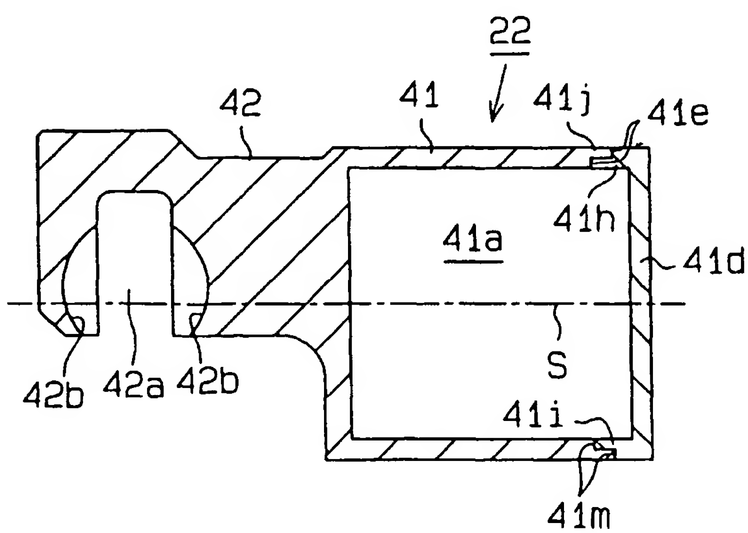

22
42
41
41j
41e
41h
41a
41d
S
42b
42a
42b
41i
41m

Fig.12